INTERACTION OF COSMIC RAYS WITH INTERSTELLAR MATTER AND POSSIBLE EXCITATION OF X-RAY LINES

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There are unexplained excess intensities in the 0.25-1 KeV energy interval of the diffuse cosmic x-ray spectrum. It is suggested here that these may be due to characteristic x-ray line spectra from interstellar matter. These spectra may have been excited by the interaction of energetic charged cosmic ray particles with interstellar matter. Since the cross section for such interactions are known only up to 40 MeV, the intensities of the x-ray lines can be estimated to within an order of magnitude only. It is suggested that the observation of cosmic x-ray lines may serve as a powerful tool for studying interstellar matter. Information about interstellar matter is difficult to obtain by other methods.

1. Introduction. There is an unexpectedly large flux of diffuse cosmic x-rays observed in the fractional KeV energy region. Several possible mechanisms have been proposed to explain these large fluxes. Some of these are listed below.

(i) Radiation from hot intergalactic gas with temperatures of (3 to 8) 10^5 degrees. (Sunyaev 1969).

(ii) Contribution from unresolved sources (Bunner, et al. 1969; Henry, et al. 1968; Ostriker, et al. 1970).

(iii) Electron capture into excited states of low energy ($\sim$ 2 MeV/nucleon) cosmic ray nuclei of charge $Z > 10$, along with cascading to the ground state during which the ions emit Doppler-broadened Lyman alpha-like radiation (Silk and Steigman 1969).

(iv) Emission from a hot galactic halo ($T \sim 10^6$ K, $R \sim 10$ Kpc, $N_e \simeq 3 \times 10^{-3}$ cm^{-3}). This is a possible mechanism for producing the high galactic latitude soft x-ray intensity (Silk 1970).

(v) Elastic scattering of intergalactic x-rays from some component of the interstellar medium (Bunner, et al. 1971).

(vi) Bremsstrahlung emission from collisions of superthermal cosmic ray protons with the ambient distribution of electrons. Three confinement regions are possible: the metagalaxy, the local group, and/or the galactic halo (Brown 1970).

(vii) Characteristic x-ray emission by atoms of elements present in the interstellar (including halo) and/or intergalactic regions (Verma 1971; Lampton, et al. 1971).

We will consider mechanism (vii) in this paper. First, let us review the relevent experimental information regarding diffuse cosmic x-rays.

2. Summary of Observations. There have been a large number of observations made to measure the flux and energy spectrum of diffuse cosmic x-rays in the 0.2 to 1 KeV energy interval (Bowyer, et al. 1968; Henry, et al. 1968; Baxter, et al. 1969a,b; Bunner et al. 1969; Hayakawa, et al. 1970; Bunner, et al. 1971; Henry, et al. 1971; Schwartz, et al. 1971; Shukla and Wilson 1971). The differential energy spectrum may be represented by a power law of the type $N(E) = N_o E^{-m}$ photons/(cm^2sec ster KeV).

Following are a few typical suggested values of N_o and m for various energy intervals:

E(KeV)	N_o	m	References
1.2 - 4.5	$9.2 \pm ^{1.2}_{1.1}$	1.28 ± 0.11	Baxter, et al. 1969b
4.5 - 12	$13.8 \pm ^{3.5}_{2.8}$	1.56 ± 0.12	Baxter, et al. 1969b
1.5 - 8		1.4 ± 0.1	Henry, et al. 1968
1 - 10	11	1.4	Bunner, et al. 1971
8 - 42	17.2	1.7 ± 0.1	Schwartz, et al. 1970
42 - 113		3.0 ± 0.3	Schwartz, et al. 1970

It seems clear that the diffuse x-ray spectrum cannot be represented by a single exponent in the 1 to 100 KeV energy interval because the exponent appears to decrease with decreasing energy. The value of m is close to 3 in the 100 KeV energy region, and is about 1.3 in the few KeV energy region. Observations of the flux of diffuse x-rays in the 0.25 to 1 KeV energy interval clearly show an excess intensity (Bowyer, et al. 1968; Henry, et al. 1968; and Bunner et al. 1969) over the extrapolated higher energy power law spectrum. Several measurements (Cooke, et al. 1969; Schwartz 1969, 1970) indicate that there is some galactic diffuse x-ray emission in the few KeV to 20 KeV energy interval. Similarly some observations indicate (Bowyer, et al. 1969; Bunner, et al. 1969, 1970; Henry et al. 1968, 1971; Palmieri, et al. 1971) that the flux of diffuse x-rays in the 0.2 to 1 KeV energy interval also has a galactic component which is correlated with measurements in the 21 cm wavelength region of the column density of hydrogen. Lampton, et al. 1971 clearly show that the x-ray background flux observed at 0.25 KeV (44 Å) should be ascribed to 44 Å line emission. The observed intensities of possible line x-rays in narrow energy bands are listed below.

$J(\sim .25\ \text{KeV}) = 25$ photons/(cm^2sec ster)(Lampton, et al. 1971)

$J(\sim .27\ \text{KeV}) = 8.5$ photons/(cm^2sec ster)(Bunner, et al. 1971)

Some observers give the differential intensities of possible line x-rays at a certain energy. Some are given below.

$J(\sim .26 \text{ KeV}) = 195 \pm 20$ photons/(cm^{2}sec ster KeV)(Bunner, et al. 1969)

$J(\sim .27 \text{ KeV}) = 330$ photons/(cm^{2}sec ster KeV)(Bunner, et al. 1971)

$J(\sim .90 \text{ KeV}) = 20 \pm 3$ photons/(cm^{2}sec ster KeV)(Bunner, et al. 1969)

Also, some line features have been observed at 7 KeV (Henry, et al. 1971; Shulman, et al. 1971; and Boldt, et al. 1971). The observed intensities and upper limits are given below.

$J(\sim 7 \text{ KeV}) = 0.5$ photons/(cm^{2}sec ster)(Schulman, et al. 1971)

$J(\sim 7 \text{ KeV}) \leq 0.06 \pm .04$ photons/(cm^{2}sec ster)(Boldt, et al. 1971)

3. Discussion. For the purpose of explaining the above intensities we should like to mention various possible processes by which an atom of an element present in the intergalactic and/or the interstellar region may be excited to emit characteristic x-ray lines. These processes are listed below.

(i) The interaction of atoms with x-ray photons by means of the photo-electric absorption of cosmic x-ray photons by neutral atoms with fluorescent x-ray line emission. Lampton, et al. (1971) have considered specifically the case of carbon atoms being excited by this process.

(ii) Excitation of neutral atoms caused by the interaction between energetic charged cosmic ray particles and atoms with emission of characteristic K and L x-rays. The interactions of protons and carbon atoms have been considered for this process by Verma (1971) using recently-measured cross sections (Garcia 1970 a,b, Bissinger, et al. 1971).

(iii) Similar emission of line x-rays should occur because of the interaction of atoms with cosmic ray nuclei of charges $Z \geq 2$ and with cosmic ray electrons and positrons. Unfortunately, no cross sections are known for these interactions.

(iv) Excitation of neutral atoms by collisions with heavy ions. Consider low energy ($E < 2$ MeV/nucleon) cosmic ray nuclei in the interstellar region. They would slow down and pick up electrons which would cascade down to lower states and form partially charged atoms (heavy ions). These may have energies of several hundreds of KeV/nucleon. These ions would interact with neutral atoms and emit line-x-rays. Only a very few cross sections for these processes are known (Der, et al. 1968).

A large amount of theoretical and experimental work is necessary to utilize the above processes in the calculation of the intensities of x-ray lines in the KeV and the fractional KeV energy regions. Three basic data are essential for these calculations.

(i) The fluxes and the energy spectra of various charged cosmic ray particles in the interstellar and intergalactic regions. These have been observed reasonably well near the earth in the 10 to 3000 MeV/ nucleon energy interval (Meyer 1969; Gloeckler and Jokipii, 1966; Fan, et al. 1968; and many others). Using certain models for solar modulation (Parker 1963; Glesson and Oxford 1968) and the data obtained near earth, one can obtain the fluxes and spectra outside the solar system with some confidence .

(ii) The cross sections for excitation x-ray lines. These are very meager. Both experimental and theoretical work needs to be done before meaningful results may be obtained.

(iii) Abundances of atoms of various elements in the intergalactic and the interstellar regions. One may assume these relative abundances to be the same as the natural universal abundances (Cameron 1968) and obtain the hydrogen abundance from measurements of the 21 cm radiation.

Here it is proposed that the excess diffuse cosmic x-rays in the fractional KeV energy band may have been produced as a result of excitation of neutral carbon, sulphur and argon atoms by cosmic rays (electrons and nuclei as well as x-ray photons) with subsequent emission of the K x-rays of carbon and the L x-rays of sulphur and argon.

It is also suggested that if the intensities of low energy cosmic rays and the cross sections for the various processes listed above for the production of x-ray lines were known, the observations of x-ray lines would provide direct information concerning abundances of elements in the interstellar and/or intergalactic regions. Similar observations of x-ray lines in the gaseous nabulae would provide the abundances of the elements in these objects.

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Research

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